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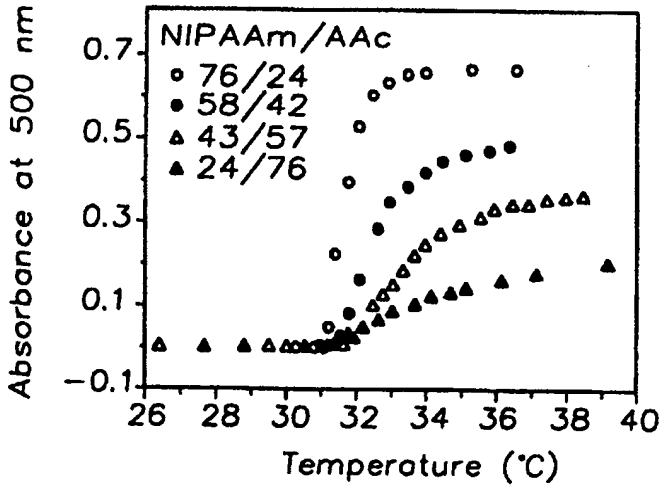
(54) Title: BLOCK AND GRAFT COPOLYMERS AND METHODS RELATING THERETO

(57) Abstract

There is disclosed block and graft copolymers which, in one embodiment, contain both a temperature-sensitive polymer component and a pH-sensitive polymer component, and the use of such copolymers for topical drug delivery to a treatment area. The block and graft copolymers may be physically mixed with one or more drugs to form a copolymer-drug mixture. This mixture may be applied to the treatment as solid particles suspended in a pharmaceutically acceptable carrier, or as a liquid which gels upon contact with the treatment area. Upon contact with the treatment area, the pH-sensitive polymer component hydrates and swells, thereby causing release of the drug from the mixture. In addition, such hydration and swelling causes the pH-sensitive polymer component to adhere to the tissue of the treatment area, thus prolonging contact time. The temperature-sensitive polymer component resists hydration and swelling of the mixture, thereby imparting a sustained and controlled release of the drug to the treatment area. In another embodiment of this invention, bloc and graft copolymers, and hydrogels thereof, are disclosed having broad industrial applicability.



Description

BLOCK AND GRAFT COPOLYMERS AND METHODS RELATING THERETO

Technical Field

This invention relates generally to block and graft copolymers, and more specifically, to block and graft copolymers which are effective in drug delivery, including copolymer-drug mixtures for the delivery and controlled release of a drug by topical application.

Background of the Invention

The effective and efficient delivery of a therapeutic drug to a patient is a goal of pharmaceutical science. Targeted drug delivery, such as topical application of a therapeutic drug to a site of action, has many advantages over systemic drug delivery. Typically, adverse side effects associated with systemic delivery may be greatly reduced when a therapeutic drug is delivered locally to the site of action by topical administration. Therapeutic drugs which are systemically administrated are dispersed relatively non-selectively throughout the patient's body and metabolized, thus reducing their therapeutic effectiveness with respect to dosage, as well as increasing the likelihood of adverse reaction. In contrast, an effective dosage of a topically administrated therapeutic drug is often significantly less than that required through systemic administration. The diminution of dosage accompanying topical administration reduces the possibility of adverse reaction to the drug. In addition, drug metabolism of topically administered therapeutics is also minimized, thereby increasing their effectiveness.

While advantageous to systemic delivery, topical administration of a therapeutic drug is far from ideal. Perhaps the greatest single drawback to topical drug administration is the actual delivery of the therapeutic drug to the tissue to be treated. The absorption of the therapeutic drug by the tissue is often a slow process, and therefore requires a relatively long contact time between the tissue and the topical formulation containing the therapeutic drug. For example, topical administration of solutions of therapeutic drugs can be rather problematic. The use of viscous solutions, gels, ointments, lotions, patches, and inserts containing therapeutic drugs is a routine alternative to the administration of therapeutics in solution. These alternative formulations serve to enhance the contact time between the therapeutic drug and the tissue to be treated, thereby increasing the effectiveness of the topical treatment.

response to temperature in aqueous solutions (see, e.g., Heskins et al., J. Macromol. Sci. Chem. A2, 1441-45, 1968). At temperatures below the LCST of NIPAAm (i.e., 32°C), polymer chains of NIPAAm hydrate to form an expanded structure, while at temperatures above the LCST the chains form a compact structure which excludes water. Thus, gel formation is due to the association of the relatively hydrophobic isopropyl groups of the NIPAAm polymer.

Temperature-sensitive polymers have been employed as vehicles for ophthalmic drug delivery. For example, block copolymers of ethylene oxide and propylene oxide have been disclosed in U.S. Patent No. 4,188,373 for this purpose. However, in this system, the concentration of the polymer must be adjusted to provide the desired solution-to-gel transition temperature. The drawback to this system is that in order to achieve a solution-to-gel temperature suitable for gelling at body temperature, the polymer must be present at a relatively low concentration. Thus, the ability to obtain a gel with the desired properties is limited by the desired physiologically useful temperature range. The necessity for a low polymer concentration, in turn, limits the amount of drug that may be administered by such a polymer system.

Polymers which are sensitive to changes in pH, such as polyacrylic acid ("polyAAc"), have also been utilized to form gels in situ, including use as vehicles in ophthalmic compositions. For example, U.S. Patent No. 4,888,168 discloses a composition containing the homopolymer polyAAc, and gel formation occurs upon the subsequent addition of an acidic component. Gel formation results in this case by an increase in viscosity associated with the protonation of the carboxylic acid groups at low pH. In water at neutral pH, the carboxy groups of polyAAc are ionized and the polymer is a liquid-in-water solution. Lowering the pH to 4.3-4.5 by the addition of an acid, such as citric acid, results in gel formation by decreasing the hydrophilicity and increasing the hydrophobicity of the polymer. An undesirable limitation of this system for use as an ophthalmic drug delivery vehicle is that gel formation requires sequential addition of two solutions (i.e., a first polyAAc solution and a second acid solution).

Due to the drawbacks of existing temperature-sensitive and pH-sensitive polymers to provide suitable vehicles for topical drug delivery, researchers have studied random copolymers containing these components for use as a vehicle for topical drug delivery. Such random copolymers, however, have not proved suitable for physiological application. In particular, random copolymers of temperature-sensitive and pH-sensitive monomers quickly lose their temperature sensitivity upon increasing the content or ratio of the pH-sensitive monomers. Thus, by employing a ratio of the pH-sensitive component sufficient to impart pH sensitivity to the random copolymer, such a ratio destroys the temperature sensitivity sought by incorporation of the temperature-sensitive

also have a LCST ranging from 20°C to 40°C at physiological pH.

The pH-sensitive polymer component of the block and graft copolymers preferably comprise a carboxylic acid-containing polymer component derived from polymerizable carboxylic acids (such as acrylic acid and methacrylic acid), and preferably are either homopolymers or copolymers containing only a limited quantity of comonomer. The temperature-sensitive polymer component has a LCST ranging from 20°C to 40°C at physiological pH, and may be a homopolymer or a random or block copolymer. The pH-sensitive or temperature-sensitive polymer components may also be lightly cross-linked, resulting in cross-linked block and graft copolymer hydrogels.

In another embodiment, the present invention is directed to a physical mixture of a block or graft copolymer with a pharmaceutically acceptable drug to form a copolymer-drug mixture. For topical application to a treatment area, the copolymer-drug mixture is applied as a solid particle suspended in a pharmaceutically acceptable carrier. Alternatively, the copolymer may be dissolved in a pharmaceutically acceptable carrier in combination with the pharmaceutically acceptable drug and applied as a liquid copolymer-drug mixture. Upon contact with the treatment area, the copolymer of the copolymer-drug mixture forms a gel. Thus, this invention also discloses compositions containing particles of the copolymer-drug mixture suspended in a pharmaceutically acceptable carrier, as well as compositions containing the copolymer and drug in combination with a pharmaceutically acceptable carrier. In yet a further embodiment, there are disclosed methods for topically delivering a drug to a treatment area by administering such a composition thereto.

In yet a further embodiment, a block or graft copolymer may be lightly cross-linked to form a hydrogel. Suitable hydrogels comprise a backbone pH-sensitive polymer component with a pendent temperature-sensitive component grafted thereto, or a backbone temperature-sensitive component with a pendent pH-sensitive component grafted thereto. In addition, block copolymer hydrogels are also disclosed comprising a pH-sensitive polymer component joined to a temperature-sensitive polymer component. Such hydrogels may contain one or more pharmaceutically acceptable drugs in, for example, a dissolved or dispersed form.

Still a further aspect of this invention involves block or graft copolymers (including hydrogels of the same) for general industrial use, including, for example, use as lubricants, moisturizers, bulk-formers and/or absorbents. In this context of the present invention, the block and graft copolymers may used over a wide pH and temperature range.

Other aspects of the present invention will become evident upon reference to the attached figures and following detailed description.

Figure 10 illustrates the temperature-sensitive behavior of 0.2 weight percent solutions of cooligoNIPAAm-BMA and oligoNIPAAm in phosphate buffered saline (pH 7.4).

Figure 11 illustrates the temperature-sensitive behavior of 0.2 weight percent solutions of graft copolymer (NIPAAm-BMA)-g-AAc, cooligoNIPAAm-BMA and homopolyAAc in phosphate buffered saline (pH 7.4).

Figure 12 illustrates the release of timolol from copolymer-drug particles of graft copolymer (NIPAAm-BMA)-g-AAc in phosphate buffered saline (pH 7.4) at 34°C.

Figure 13 illustrates the release of timolol from cast films of copolymer-drug mixtures for various graft copolymers of (NIPAAm-BMA)-g-AAc for various compositions of NIPAA-BMA co-oligomer in phosphate buffered saline (pH 7.4) at 34°C.

Figure 14 illustrates the synthesis of a representative graft copolymer hydrogel of this invention.

Figure 15 illustrates the degree of grafting for representative graft copolymer hydrogels.

Figure 16 illustrates the swelling ratios for representative graft copolymer hydrogels (open circle: 0.5 weight percent cross-linker, 58.97% grafting; filled square: 2.0 weight percent cross-linker, 48.41% grafting; open square: 2.0 weight percent cross-linker, 65.27% grafting).

Figure 17 illustrates the rate of release of timolol from cast films of copolymer-drug mixtures for several graft copolymer hydrogels of (NIPAAm-BMA)-g-AAc in phosphate buffered saline (pH 7.4) at 34°C.

Figure 18 illustrates the temperature-sensitive behavior of 0.2 weight percent solution of a random copolymer of NIPAAm and AAc (89 mole % NIPAAm) at pH 4.0 and pH 7.4.

Figure 19 illustrates the temperature-sensitive behavior of a 0.5 weight percent solution of a commercially available block copolymer of ethylene oxide and propylene oxide ("EO/PO/EO").

Figure 20 illustrates the temperature-sensitive behavior of a 2.5 weight percent solution of a graft copolymer of the EO/PO/EO block copolymer of Figure 19 grafted to a homopolymer backbone of AAc (*i.e.*, EO/PO/EO-g-AAc).

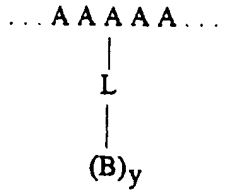
Figure 21 illustrates the drug release (timolol maleate) from graft copolymers of EO/PO/EO-g-AAc at varying ratios of EO/PO/EP to AAc (*i.e.*, 10:90, 20:80 and 30:70). For comparison purposes, drug release from a homopolymer of AAc,

the copolymer may be dissolved in a pharmaceutically acceptable carrier in combination with the drug and administered in the form of a liquid copolymer-drug mixture, the copolymer component of which forms a gel upon contact with the treatment area. The physical changes which occur upon contact with the treatment area are discussed in greater detail below.

As used in the context of this invention, the term "drug" includes the definition set forth in 21 C.F.R. § 201(g)(1), "Federal Food, Drug and Cosmetic Act Requirements relating to Drugs for Human and Animal Use" (hereby incorporated by reference). Under this definition, a drug means (a) articles recognized in the official United States Pharmacopeia, official Homeopathic Pharmacopeia of the United States, or official National Formulary, or any supplement thereof; and (b) articles intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease in man or other animals; and (c) articles (other than food) intended to affect the structure or any function of the body of man or other animals; and (d) articles intended for use as a component of any articles specified in clause (a), (b) or (c) above; but does not include devices or their components, parts or accessories. Water is specifically intended to be included in the definition of the term drug as used herein. The term "cosmetic composition" includes compositions for skin care, hair care, care of nails, and toiletries, perfumes and fragrances. The term "superabsorbent" means a hydrogel which, starting from a dry material, will imbibe about 20 times its own weight of aqueous fluid (J. Gross, Absorbent Polymer Technology, L. Brannon-Peppas and R. Harland, ed., Elsevier, New York, New York, 1990, page 9)(incorporated herein by reference)

As mentioned above, in the practice of one embodiment of this invention, block and graft copolymers are used as a vehicle for the delivery of one or more drugs. The graft and block copolymers accomplish controlled and sustained drug release from the copolymer-drug mixtures through the physical properties of the component parts of the copolymer. Specifically, the block and graft copolymers of the present invention are comprised of two polymer components: a temperature-sensitive polymer component and a pH-sensitive polymer component. Upon contact with the treatment area, the pH-sensitive polymer component of the graft and block copolymers or hydrogels either hydrate and swell, or collapse, thereby causing release of the drug from the copolymer-drug mixtures. Hydration and swelling of the pH-sensitive polymer component is due to the uptake of both water and ions from the treatment area. For example, when the pH-sensitive polymer component is a carboxylic acid-containing polymer (such as polyAAc), the carboxylic acid groups ("COOH") are ionized by the uptake of cations (such as Na^+ or K^+) from the treatment area to yield neutralized carboxylic acid moieties (i.e., COO^-Na^+). Ionization of the carboxylic acid groups is accompanied by the uptake of water

above, polyAAc is a homopolymer of AAc moieties. Consequently, the polyAAc polymer chain is substituted with pendant carboxylic acid groups. The covalent coupling of a second, different homopolymer to one or more of these pendant carboxylic acid groups provides a "graft copolymer." Essentially, the second polymer is grafted onto the first. Thus, graft copolymers have a "backbone" polymer onto which one or more "pendant" polymers have been covalently attached. The nature of the graft copolymer may vary considerably depending upon the degree of substitution of the pendant polymers onto the backbone polymer. A graft copolymer having backbone homopolymer A onto which pendant homopolymer B is attached may be schematically represented by the following formula:



where ". . . AAAAA . . ." is a homopolymer of monomer A, $(B)_y$ is a homopolymer of y monomers of B, and L is a suitable covalent bond.

The block and graft copolymers discussed above contain homopolymers A and B, which represent the temperature-sensitive polymer components and pH-sensitive polymer components of this invention. In addition, the block and graft copolymers of this invention may also be derived from polymers other than homopolymers. For example, rather than grafting pendant homopolymer B to backbone homopolymer A, copolymer CD may be grafted to homopolymer backbone A to yield a graft copolymer where the pendant polymer is itself a copolymer. In this case, homopolymer A corresponds to the pH-sensitive polymer component and copolymer CD is either a random copolymer or a block copolymer of comonomers C and D, and corresponds to the temperature-sensitive copolymer component. Alternatively, the backbone polymer may be the copolymer CD (which represents the temperature-sensitive polymer component), with the pendant polymer being the homopolymer A (which represents the pH-sensitive polymer component). The same is true for block copolymers--that is, copolymer CD (which represents the temperature-sensitive polymer component) may be used in combination with homopolymer A (which represents the pH-sensitive polymer component). While the pH-sensitive polymer component has generally been referred to as a homopolymer in the above discussion, the pH-sensitive

In the context of drug delivery, block and graft copolymers with LCSTs outside of the 20°C to 40°C range are generally not suitable for use in the practice of this invention. Copolymers with LCSTs below 20°C, in addition to being difficult to administer, are extremely resistant to dissolution and therefore are ineffective in drug delivery. Copolymers with LCSTs above 40°C will rapidly and completely dissolve at physiological temperature and pH, and therefore are ineffective in retarding drug delivery as a consequence of short residence period at the treatment area. (This aspect of the invention is discussed in greater detail below with regard to the bioadhesive properties of the block and graft copolymers of this invention.)

As mentioned above, the temperature-sensitive polymer component of the block and graft copolymers of this invention may be derived from homopolymers or copolymers. In either case, the temperature-sensitive polymer component has a LCST in the same range as that of the block and graft copolymers of this invention (i.e., for use as a drug delivery vehicle, in the range from 20°C to 40°C, preferably in the range from 26°C to 34°C, and more preferably from 28°C to 32°C within the above-identified pH ranges). Thus, for drug delivery use, suitable temperature-sensitive polymers of this invention have LCSTs ranging from 20°C to 40°C, and confer an LCST of the same range upon their respective block and graft copolymers. In the context of this invention, the LCSTs of the temperature-sensitive polymers are measured at an aqueous solution concentration below 1% by weight, preferably from 0.01% to 0.5% by weight, and more preferably from 0.1% to 0.3% by weight.

Temperature-sensitive polymers of this invention may contain ester ether, amide, alcohol, and acid groups. These polymers may be synthesized by the polymerization of vinyl monomers such as acrylamide or N-isopropylacrylamide which provide polyacrylamide and poly(N-isopropylacrylamide), respectively, or esters of acrylic acid or methacrylic acid, for example, butyl acrylate or butyl methacrylate which provide poly(butyl acrylate) or poly(butyl methacrylate), respectively. Similarly, polymerization of cyclic ether monomers such as ethylene oxide provide polyethers and polymerization of vinyl acetate followed by hydrolysis provides polyalcohols. Suitable esters include esters of acrylic acid and its various derivatives such as methacrylic acid. Suitable ethers include ethylene oxide, propylene oxide, and vinyl methyl ether. Suitable alcohols include hydroxypropyl acrylate, and vinyl alcohol. Suitable amides include N-substituted acrylamides, N-vinylpyrrolidone, N-vinylacetamide, N-vinyl proprionamide, N-vinylbutyramide, and ethyl oxazoline. Thus, block and graft copolymers of the present invention include temperature-sensitive polymer components containing polyesters, polyethers, polyalcohols, and polyamides. Preferably, the temperature-sensitive polymer components are selected from block copolymer of

of representative copolymers having various Pluronics® grafted to polyAAc are described in detail in Example 6).

As mentioned above, the pH-sensitive polymer component of the graft and block copolymers of the present invention drives dissolution, as well as imparting bioadhesive properties and, in some instances, drug binding characteristics to the block and graft copolymer. As used herein, the term "bioadhesive" refers to the ability of the copolymer-drug mixture to adhere to the tissue of the treatment area upon hydration and swelling of the mixture. For example, when the treatment area is the eye, adhesion between the copolymer-drug mixture and the surface of the eye is due to the attractive interaction between chemical functional groups of the copolymer and eye's surface. The ionic nature of the pH-sensitive polymer component provides an adhesive interaction with the surface of the eye, thereby prolonging the residence time of the copolymer-drug mixture on the eye's surface.

In one embodiment, the pH-sensitive polymer component is a carboxylic acid-containing polymer, and may be derived from polymerizable carboxylic acids, including acrylic acid, methacrylic acid, ethacrylic acid, β-methylacrylic acid, cis-α-methylcrotonic acid, trans-α-methylcrotonic acid, α-butylcrotonic acid, α-phenylacrylic acid, α-benzylacrylic acid, α-cyclohexylacrylic acid, β-phenylacrylic acid, coumaric acid, and umbellic acid. Carboxymethylcellulose may also be a suitable carboxylic acid-containing polymer. In a preferred embodiment, the carboxylic acid-containing polymer is polyAAc.

In another embodiment, the pH-sensitive polymer component is an amine-containing, a phosphate-containing, a sulfate-containing, or a sulfonate-containing polymer component, or mixtures thereof. In a preferred embodiment, the pH-sensitive polymer component is an amine-containing or a phosphate-containing polymer component.

As described above, the pH-sensitive polymer component imparts bioadhesion to the block and graft copolymers of the present invention. In the case of carboxylic acid-containing polymer components, on contact with a treatment area, such as the eye or other mucosal tissue, the carboxylic acid moieties ionize and become carboxylate salts, for example, sodium carboxylate or potassium carboxylate. The transformation from carboxylic acid to carboxylate salt upon contact with the treatment areas results in hydration of the copolymer-drug mixtures. The bioadhesive properties of the mixtures are imparted upon hydration. Prior to hydration, the carboxylic acid form may also be bioadhesive. Ionization to the carboxylate salt causes the gel to swell and act "sticky", but it may lose its stickiness as it further hydrates. Similarly, the amine-, phosphate-, sulfate-, and sulfonate-containing polymer components are also capable of

solution containing the drug, and then precipitating the copolymer-drug solution into a non-solvent for the copolymer and drug, thus obtaining the copolymer-drug particles. (For example, the formation of particles of the drug timolol-hydrogen maleate and the copolymer NIPAAm-b-AAc is described in Example 1C.) Alternatively, the block or graft copolymer may be dissolved in a solution containing the drug, or dissolved in a solution to which the drug is then added, to yield a liquid copolymer-drug mixture. Such a solution may be further concentrated, or may be dried to yield, for example, a solid film. Suitable solutions include both aqueous and non-aqueous solvents. In one embodiment, the solution may contain at least 10% by weight of a non-aqueous solvent, and in a further embodiment may contain at least 99% by weight of a non-aqueous solvent.

As for the synthesis of the block and graft copolymers, such polymers may generally be synthesized by covalent coupling of a suitably reactive temperature-sensitive polymer component to a suitably reactive pH-sensitive polymer component. The covalent link between the two polymer components should be resistant to cleavage under conditions encountered following topical administration. Accordingly, suitable covalent linkages include amide, ester, ether, thioester, thioether, urea, urethane and amine linkages. Such linkages result from the coupling of a suitably reactive temperature-sensitive polymer component with a complementary pH-sensitive polymer component. For example, an amide linkage may be prepared either by coupling an amino-terminated temperature-sensitive polymer component with a carboxylic acid-modified pH-sensitive polymer component, or by the coupling of an amino-terminated pH-sensitive polymer component with a carboxylic acid-terminated temperature-sensitive polymer component. Other linkages may be similarly prepared by standard techniques. For example, representative syntheses of an amino-terminated pH-sensitive polymer (polyAAc) and a carboxylic acid-modified temperature-sensitive polymer (NIPAAm) are described in detail in Example 1A1 and 1A2, respectively. The coupling of these species to provide an amide-linked block copolymer is described in Example 1A3. A representative synthesis of an amino-terminated temperature-sensitive polymer component and its covalent coupling to a carboxylic acid-modified pH-sensitive polymer component to yield an amide-linked graft copolymer is described in Example 2A2.

Alternatively, graft copolymers of the present invention may be synthesized by the copolymerization of a suitable pH-sensitive monomer with a temperature-sensitive macromonomer. A representative synthesis of such a graft copolymer is described in detail in Example 2A1.

In one embodiment, the copolymers of the present invention are block copolymers. Block copolymers may be synthesized by the covalent coupling of the

described in Example 2, and a representative synthesis of a graft copolymer derived from the coupling of a pendant temperature-sensitive copolymer to a pH-sensitive homopolymer backbone is presented in Example 3. In a preferred embodiment, the graft copolymer has a pH-sensitive homopolymer backbone of polyAAc with pendent temperature-sensitive Pluronics® (i.e., block copolymers of ethylene oxide and propylene oxide) grafted thereto, as disclosed in Example 6.

The graft copolymers of the present invention have either a pH-sensitive polymer backbone with one or more pendant temperature-sensitive polymer components, or a temperature-sensitive polymer backbone with one or more pendant pH-sensitive polymer components. The degree of substitution of the pendant polymer components on the backbone polymer may be controlled by the chemical coupling reaction. For example, by adjusting the ratio of pendant groups to be reacted with the backbone polymer, the properties of the graft copolymer product may be controlled and optimized. Graft copolymers with higher ratios of temperature-sensitive polymer components will possess relatively slower dissolution rates. Accordingly, a balance in the pH-sensitive and temperature-sensitive polymer components may provide an optimum copolymer which exhibits both preferred temperature-sensitive behavior with respect to dissolution and drug release, as well as preferred bioadhesion so as to provide extended residence time upon administration.

The graft copolymers of the present invention preferably have average molecular weights in the range from 100,000 to 600,000, and more preferably in the range from 250,000 to 500,000. In an alternative embodiment, the graft copolymers of this invention may have average molecular weights in the range from 50,000 to 1,000,000. In addition, the temperature-sensitive polymer component preferably constitutes at least 5%-10% by weight of the graft copolymer.

In a further embodiment of the present invention, the block and graft copolymers may be lightly cross-linked. These block and graft copolymers are referred to as "hydrogels." In one embodiment, the backbone polymer component is a cross-linked pH-sensitive polymer component with one or more pendant temperature-sensitive polymer components. In a preferred embodiment, the hydrogel is derived from a cross-linked pH-sensitive polymer backbone. Alternatively, the pH-sensitive polymer components of a block copolymer may be lightly cross-linked. Suitable cross-linking agents are well known and include (but not limited to) relatively "short" cross-linkers, such as methylene-bis-acrylamide and ethylene glycol dimethacrylate (EGDMA), as well as relative "long" cross-linkers, such as polyethylene glycol dimethacrylate (PEGDMA).

The cross-linked hydrogels of the block and graft copolymers effectively prevent rapid dissolution of the copolymer, while at the same time do not preclude

As described above, the copolymer-drug particles may be suspended in a pharmaceutically acceptable carrier. In one embodiment, the pharmaceutically acceptable carrier may be a volatile carrier. Volatile carriers serve to transport the solid particles of the copolymer-drug particles to the treatment area and, upon contact with the treatment area, rapidly evaporate, to effectively deposit the particles on the treatment area. Suitable volatile carriers include fluorocarbon propellants (such as trichlorodifluoromethane and dichlorodifluoromethane) and such propellants may generally be present over a range from 5 to 20 times by weight the amount of copolymer-drug particles. The suspension of the copolymer-drug particles in the volatile carrier may be administered to the treatment area by any device suitable for effective delivery of the suspension. Effective delivery of the suspension preferably includes accurate and reproducible dosing of the copolymer-drug particles, and include metered dose nebulizers and devices which deliver the suspension as droplets (such as eye droppers).

In another embodiment, the copolymer-drug particles of the present invention may be administered as a suspension of particles in an aqueous carrier including distilled or sterile water. For ophthalmic administration, the osmolality of these aqueous compositions are preferably adjusted to physiological osmolality for physical comfort. Such aqueous compositions may have an osmolality of from about 50 to about 400 mOsM, preferably from about 100 to 300 mOsM, and more preferably about 150 mOsM. A suitable osmolality may be achieved by addition of a physiologically acceptable material such as a sugar or other nonionic compound.

In still a further embodiment, the copolymers of the present invention may be formulated for administration in liquid form by dissolving one or more of the copolymers in a pharmaceutically acceptable carrier. In one embodiment, the copolymer is present in these formulations at a sufficiently high concentration such that the formulation will gel upon contact with the treatment area. Typically, suitable concentrations of the copolymer in these formulations range from 0.1% to 20% by weight of the formulation, and preferably from 0.5% to 10% by weight of the formulation. In these formulations, the pharmaceutically acceptable drug may be present in a soluble or suspended form, or bound to a carrier. When the formulation gels upon contact with the treatment area, at least a portion of the drug present within the formulation is trapped within the gel.

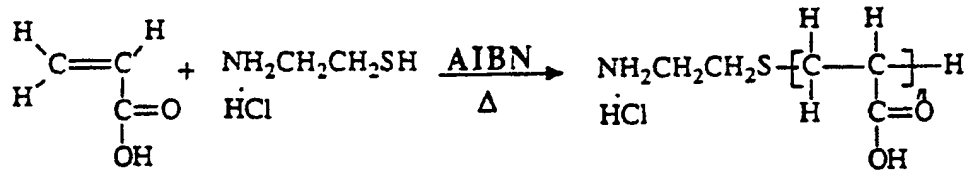
In yet further embodiments, the copolymer-drug mixtures of this invention may be formulated as a solution, cream, gel, ointment, tablet, capsule or suppository. To this end, suppository formulations may be particularly suited for rectal administration of the copolymer-drug mixtures, while tablet and capsule forms are

15. The block and graft copolymers, and hydrogels thereof, may also be used to provide moisture to, retain moisture at, or provide hydration to, the treatment area.

While the above disclosure is generally directed to block and graft copolymers comprising pH-sensitive and temperature-sensitive components, it should be recognized that polymer components which are sensitive to other environmental triggers may be employed. Thus, as used in the context of this invention, an environmentally sensitive polymer is a polymer that reversibly undergoes a change from primarily hydrophilic to primarily hydrophobic in response to a change in an environmental condition, such as temperature, pH, solvent or solvent concentration, ions or ionic concentration, light, or pressure. Materials and gels which exhibit these changes are known in the art. Tanaka, Physical Review Letters 40(12):820-823, 1978; Tanaka et al., Physical Review Letters 38(14):771-774, 1978; Tanaka et al, Physical Review Letters 5 45:1636, 1980; Ilavsky, Macromolecules 15:782, 1982; Hrouz et al, Europ. Polymer J., 17:361, 1981; Ohmine et al, J. Chem Phys. 8:6379, 1984; Tanaka et al, Science 218:462, 1982; Ilavsky et al, Polymer Bull. 7:107, 1982; Gehrke, Responsive Gels: Volume Transitions II; ed K. Dusek, Springer-Verlag, New York, pp. 81-114, 1993; Li et al, Ann. Rev. Mat. Sci. 22:243-277, 1992; Galaev et al, Enzyme Microb. Technol. 15:354-366, 1993 and Taylor et al, J. Polymer Sci. 13:2551-2570, 1975 (all of which are incorporated herein by reference). This change in hydrophilic to hydrophobic character may be evidenced by a decrease in transmission of light (cloud point), change in viscosity or swelling or collapse. As mentioned above, if an environmentally sensitive polymer undergoes the change in response to a change in temperature, it is a temperature-sensitive polymer, and if it undergoes the change in response to a change in pH, it is a pH-sensitive polymer.

Accordingly, in another embodiment of this invention, block and graft copolymers are disclosed which contain environmentally-sensitive polymer components which are responsive to different triggers. For example, block and graft copolymers containing two different pH-sensitive polymer components, or two different temperature-sensitive polymer components, may be used. Alternatively, the block and graft copolymers of this invention may contain, for example, a light-sensitive polymer component in combination with either a temperature-sensitive or pH-sensitive polymer component, or in combination with a different light-sensitive polymer, or in combination with a polymer component sensitive to other triggers

The following examples are provided for purposes of illustration, not limitation.



The molecular weights of the oligomers were determined by end-group analysis as disclosed in Hazra et al., Analytical Biochemistry 137: 437-43 (1984). In this method, 2,4,6-trinitrobenzenesulfonic acid (TNBS) was reacted with the amino end group, and the absorbance of the product at 420 nm was measured. A calibration curve was established using three different amines with different numbers of carbons as follows: $H_2N(CH_2)_2COOH$, $H_2N(CH_2)_3COOH$, and $H_2N(CH_2)_5COOH$. Table 1 summarizes the synthetic conditions and results for the polymerizations of AAc.

Table 1: Polymerization of AAc

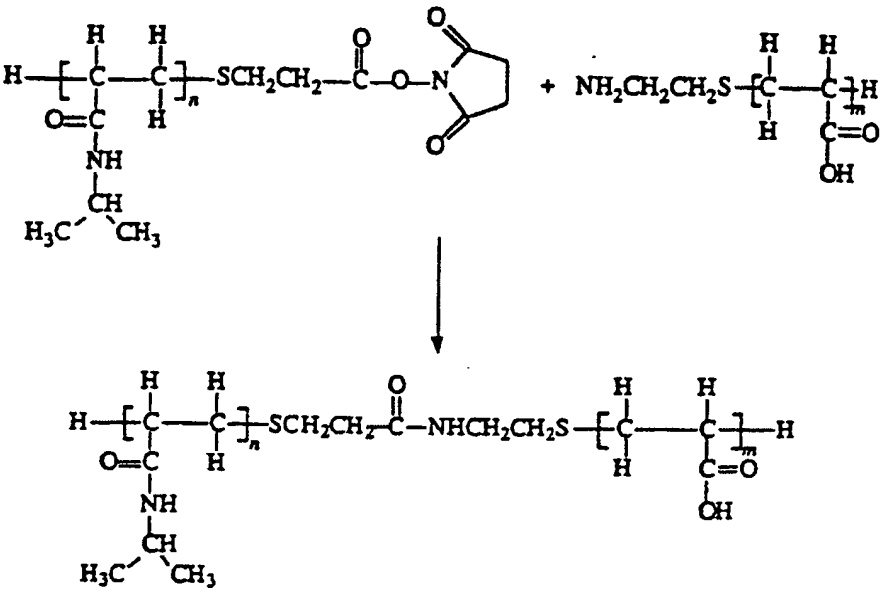
AAc:AIBN:AET:HCl (mole)	Polymn. Time (h)	Yield (%w/w)	MW[a]
100:1:1	3.0	90	15200
100:1:2	3.5	73	6600
100:1:4	4.0	77	3500
100:1:6	4.0	55	2200
100:1:8	4.0	56	1500
100:1:10	4.0	42	1200

*Concentration of monomer in methanol: 3.5 mole/L, polymerization temperature: 60°C;
[a]The molecular weight (MW) of the oligomer was determined by TNBS.

The molecular weight of the oligomers was controlled by changing the ratio of monomer to chain transfer reagent, molecular weights ranging from 1200 to 15,200 were obtained. From the data in the table shown above, the chain transfer constant for this system was calculated to be $C_S = 0.62$. These oligomers were used for the further synthesis of the block copolymer of NIPAAm-b-AAc.

3. Synthesis of Block Copolymer NIPAAm-b-AAc

The block copolymer of NIPAAm-b-AAc was synthesized by coupling the amino-terminal group of the oligoAAc with the NHS-activated carboxyl group of the oligoNIPAAm by reaction in DMF at 60°C overnight. The synthesis of the block copolymers of NIPAAm-b-AAc is represented schematically below.



The reaction mixture was poured into ethyl acetate to precipitate the block copolymer product and unreacted oligoAAc. The unreacted oligoNIPAAm is soluble and remained in solution. The precipitate containing the product block copolymer and unreacted oligoAAc was then collected by filtration and dissolved in pH 7.4 phosphate buffer. The addition of saturated aqueous ammonium sulfate solution precipitated the block copolymer which was collected by filtration and washed with dilute hydrochloric acid to remove residual ammonium sulfate. The block copolymer was dried in a vacuum oven overnight. Table 2 presents the results of the block copolymer synthesis.

(4,000 for oligoNIPAAm and 15,000 for oligoAAc) was used to prepare exemplary block copolymer-drug particles. A solution of 0.6 g of the copolymer and 6.0 mg of the drug in 8 mL of methanol was prepared. This solution was precipitated into 800 ml of ether. The precipitated block copolymer-drug particles were recovered by filtration, washed three times with ether and dried under vacuum at room temperature. The recovery was 65% with a drug content of 1.1 wt%. In a control experiment, homopolymer (polyAAc)-drug particles were prepared in the same procedure as described above, except homopolyAAc having a molecular weight of 250,000 was used instead of the block copolymer NIPAAm-b-AAc. In this experiment, the percent recovery was 93% with a drug content of 1%. These materials were ground into small particles (ca. 20-40μ) for the drug release study described below.

2. Drug Release

Solutions of 10 mg of the block copolymer with 1.1 wt% drug prepared as described above and polyAAc with 1% drug in 15 mL of PBS buffer (pH 7.4) were prepared. The solutions were well-stirred during the drug release process. The amount of drug release from the polymers was determined by circulating the buffer to an absorbance spectrophotometer where the absorbance of the drug solution at 294 nm was measured as a function of time. The drug release results are presented in Figure 2.

Despite the higher molecular weight of homopolyAAc (molecular weight 15,000), the drug release from the block copolymer NIPAAm-b-AAc (molecular weight 4,000) was significantly slower. Referring to Figure 2 above, 80% drug release from the block copolymer requires 12 minutes, while the same extent of drug release occurs in 5 minutes with homopolyAAc. For comparative purposes, release data for graft copolymer NIPAAm-g-AAc and random copolymer NIPAAm-AAc is presented in Figure 5. Note that 80% drug release is achieved in 8 minutes for the graft copolymer NIPAAm-g-AAc (20% by weight NIPAAm) and in 3 minutes for the random copolymer NIPAAm-AAc (30% by weight NIPAAm).

The slower release rate from the block copolymer may be attributed to its temperature-sensitive component, NIPAAm. At 34°C, the NIPAAm component aggregates and becomes hydrophobic, resulting in a kind of gelation of the block copolymer-drug mixture, leading to a retardation in both dissolution rate and drug release rate. In fact, it was found that the block copolymer was not quite soluble but only swollen in PBS buffer (pH 7.4) at 34°C.

Figure 2 shows that a reduction in drug release rate is obtained compared to homopolyAAc by using the block copolymer as a matrix, even for a block copolymer with a total molecular weight of only 19,000 and only 20 wt% of NIPAAm component.

a. Synthesis of Amino-Terminated OligoNIPAAm and its Corresponding Macromonomer

OligoNIPAAm was synthesized by free radical polymerization of NIPAAm in methanol solution (2.5 M NIPAAm) using AIBN and AET-HCl as initiator and chain transfer reagent, respectively. The polymerization was carried out at 60°C for 22 hours. The results for two representative syntheses are presented below in Table 3.

Table 3: Polymerization of NIPAAm

NIPAAm:AIBN:AET-HCl	Yield	MW[a]
100:1:12	59.7	3300
100:1:8[b]	68.5	2200

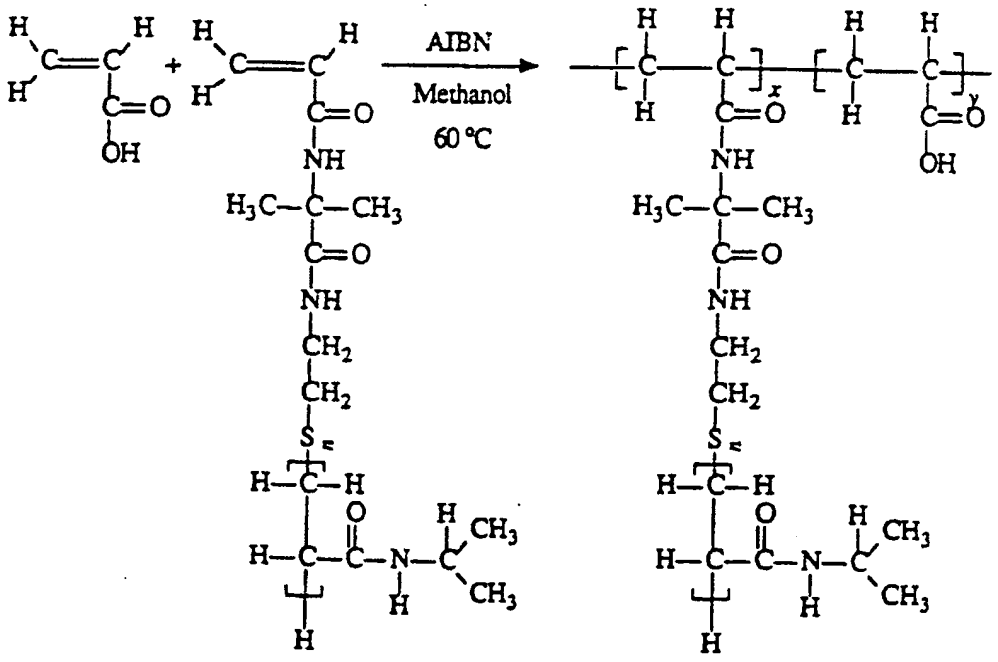
[a]Molecular weight was estimated by conductometric titration with sodium hydroxide;
[b]pH of the monomer solution was adjusted to 1.0 prior to polymerization.

The macromonomer of NIPAAm may be prepared by reaction of an amino-terminated oligoNIPAAm with vinyl azlactone. In a representative synthesis, a solution of 5.0 g (2.27 mmol) amino-terminated oligoNIPAAm (MW 2200) and 0.94 g (6.79 mmol) vinylazlactone in 120 mL tetrahydrofuran was stirred at 40°C for 16 hours. The reaction mixture was precipitated into 1000 mL diethyl ether and the resulting precipitate was collected by filtration. The product was isolated in 82% yield. The synthesis of the macromonomer of NIPAAm is presented schematically below.

Table 4: Copolymerization of AAc and Macromonomer NIPAAm

Feed		Copolymer	
W_{AAc}/W_{NIPAAm}	Yield	W_{AAc}/W_{NIPAAm}	M_{AAc}/M_{NIPAAm}
60/40	68	55/45	97/3
80/20	66	72/28	99/1

The synthesis of the graft copolymer NIPAAm-g-AAc by the copolymerization method is represented schematically below.



Macromonomer of NIPAAm poly (NIPAAm-g-AAc)

B. Temperature-Sensitive Behavior of the Graft Copolymers

The thermal-sensitivity of the graft copolymers prepared by copolymerization and conjugation exhibit similar temperature sensitivity. The graft copolymers prepared by direct conjugation with 20% to 50% NIPAAm demonstrate phase separation between 30°C and 35°C and are most appropriate as vehicles for drug delivery. The temperature-sensitive behavior of the graft copolymers NIPAAm-g-AAc is presented in Figure 3. The graft copolymer compositions begin to phase separate around 32°C and their response to temperature is rather broad due to the influence of the backbone COO^-Na^+ moieties.

C. Drug Loading and Release from the Graft Copolymers

1. Drug Loading

Graft copolymer drug loading was performed as described generally in Example 1C1. Solution of 0.5 g of the graft copolymer and 5.0 mg of timolol maleate in 8 ml methanol was precipitated into 800 mL of diethyl ether. White, sphere-like particles of the graft copolymer with an average 2-3 mm diameter were obtained. The percent recovery was 92% with 1 wt% of drug loaded The material was ground into ca. 20-40μ particles for the drug release experiment.

2. Drug Release

A suspension of 40 mg graft copolymer NIPAAm-g-AAc/timolol mixture in 40 mL of PBS buffer was prepared. As described above in Example 1C2, the amount of drug released from the complex was determined as a function of time by determining the absorbance of the solution. The results of the drug release at 34°C and 37°C are presented in Figures 4 and 5, respectively.

As shown in Figure 4, drug release from graft copolymers is slower than from particles of random copolymers with similar compositions at 34°C. Increasing the temperature of the release medium to 37°C (Figure 5) slows down the release rate from the graft copolymers but not the release rate from the random copolymers. The results indicate that the increased hydrophobicity of the graft chains contributes to the slower release of drug.

Alternatively, copolymer dissolution and drug release may be determined simultaneously by casting the copolymer-drug mixture on a glass disc. In this method, a copolymer-drug mixture is cast onto a glass disc forming a film. The coated glass disc is then suspended in an appropriate medium such as phosphate buffered saline, pH 7.4, or distilled water. The temperature of the drug released into the medium may also be controlled to investigate temperature effects on dissolution and drug release. The

A. Synthesis and Characterization of Graft Copolymers NIPAAm-BMA-g-AAc

Graft copolymers (NIPAAm-BMA-g-AAc) comprising a temperature-sensitive copolymer component (NIPAAm-BMA) and a pH-sensitive homopolymer component (AAc) were synthesized from oligomers of NIPAAm-BMA and AAc. The graft copolymers were synthesized by covalently coupling an amino-terminated NIPAAm-BMA oligomer (see 1. below) to one or more carboxyl groups on the polyAAc backbone (see 3. below).

1. Synthesis of Amino-Terminated Co-oligo(NIPAAm-BMA)

Copolymerization of NIPAAm with a more hydrophobic monomer produces a copolymer with a lower LCST (cloud point) than the homopolymer polyNIPAAm. A co-oligomer with a lower LCST was synthesized by copolymerization of NIPAAm with a more hydrophobic comonomer, butylmethacrylate (BMA) in the presence of chain transfer reagent, 2-aminoethanethiol hydrochloride (AET-HCl) to obtain an amino-terminated co-oligomer NIPAAm-BMA. The co-oligomer was then grafted onto polyAAc.

In a representative synthesis, 3 mole% of BMA and 97 mole% of NIPAAm were charged with the molar ratio of monomer to initiator (AIBN) to chain transfer reagent (AET-HCl) of 100:1:5. 40 mL of DMF was used as solvent and the polymerization was performed at 60°C for 1 hour. The co-oligomer thus formed was recovered by precipitating into ether. The yield was 45% and the number average molecular weight of the co-oligomer determined by vapor pressure osmometry (VPO) was 3100. The BMA composition in the co-oligomer was determined to be 4 mole% by ^{1}H-NMR. The synthesis of co-oligomer NIPAAm-BMA is represented schematically below.

3. Synthesis of Graft Copolymer of Co-oligo NIPAAm-BMA-g-AAc

The graft copolymer of co-oligo[NIPAAm-BMA]-g-AAc was synthesized by reaction of the amino group of the amino-terminated co-oligomer NIPAAm-BMA with the carboxyl group(s) on the polyAAc backbone. Amide bond formation was achieved in the presence of dicyclohexylcarbodiimide (DCC) at room temperature for 24 hours. The weight ratio of polyAAc to co-oligomer used for the reaction was 1, i.e., 50/50 (wt/wt) varied from 50/50 to 95/5 (wt/wt). The graft copolymer was recovered in 75%-90% yield by precipitation into tetrahydrofuran (THF).

Table 6: Graft Copolymer Synthesis Results

Sample No.	Co-oligomer in feed in wt%	Yield	Co-oligomer in copolymer[a] wt%
1	50	91	45.5
2	20	80	19.0
3	30	77	28.0
4	10	74	8.9
5	5	82	4.5

[a]Compositions of co-oligomer in the graft copolymer was determined by back titration of the polyAAc component.

The synthesis of graft copolymers (NIPAAm-BMA)-g-AAc is represented schematically below.

starts its phase transition in PBS at 28°C and at 34°C the phase transition is almost complete. The thermally-induced phase transition temperature for the above-described graft copolymer is significantly lowered by the introduction of hydrophobic comonomer units (BMA) into the oligoNIPAAm. At eye temperature (34°C), the graft co-oligomer chain becomes sufficiently hydrophobic to significantly reduce the drug release rate.

C. Drug Loading and Release from Graft Copolymers

1. Drug Loading

Graft copolymer drug loading was performed as described generally in Example 1C1. A solution of 0.5 g of the graft copolymer and 5.0 mg of timolol-maleate in 8 ml methanol was precipitated into 800 mL of diethyl ether. White, sphere-like particles of the graft copolymer with an average 2-3 mm diameter were obtained. The percent recovery was 92% with 1 wt% of drug loaded. The material was ground into ca. 10-20μ particles for the drug release experiment.

2. Drug Release

A suspension of 40 mg graft copolymer (NIPAAm-BMA)-g-AAc/drug mixture in 40 mL of PBS buffer was prepared. As described above in Example 1C2, the amount of drug released from the mixture was determined as a function of time by determining the absorbance of the solution. The results of the drug release are presented in Figure 12. For comparison, the drug release data for graft copolymer NIPAAm-g-AAc and random copolymer NIPAAm-AAC is presented in Figure 5.

Referring to Figures 5 and 12, complete release of the drug from graft copolymer poly([NIPAAm-BMA]-g-AAc) requires 80 to 90 minutes, while complete release from the graft copolymers which have pure oligoNIPAAm as the graft component requires only about 20 minutes. The conclusion is that a more hydrophobic grafted oligomer provides for slower release rates. By increasing the hydrophobicity of the graft copolymer, the drug release rate is reduced significantly compared to polyAAc. Graft copolymers with less than 20% by weight co-oligomer are erodible and show a reduced rate of drug release. Graft copolymers with greater than 20% by weight co-oligomer also significantly reduce the drug release rate, but these copolymers are not erodible.

The drug release from copolymer-drug mixture films cast on glass disc is presented in Figure 13. Figure 13 compares the rates of release of timolol from cast films of drug complexes of graft copolymers [NIPAAm-BMA]-g-AAc of varying cooligomer NIPAAm-BMA content with homopoly AAc. The data presented compares drug release into phosphate buffered saline (pH 7.4) at 34°C for copolymers derived

degassed with nitrogen and injected into the 1.5 mm space between two glass plates. Polymerization was continued for 17 hours at 60°C. The resulting hydrogel sheet was washed by suspending the sheet in an ethanol bath for 48 hours. Disc-shaped hydrogels were obtained by cutting the gel sheet with a cork borer (15 mm diameter), followed by drying for 48 hours in air and for 24 hours under vacuum.

To graft the temperature-sensitive polymer component to the pH-sensitive cross-linked hydrogel, the dried gels prepared as described above, were swollen in methanol solutions containing varying amounts of amino-terminated NIPAAm, molecular weight 3,300 g/mol (solution concentrations from 0.65 g/L to 32.89 g/L). The swelling was carried out at room temperature for 48 hours. The uptake of amino-terminated NIPAAm by the gels was calculated from the equilibrium swollen volume of the gel. The hydrogel absorbed amino-terminated NIPAAm was then grafted (covalently coupled) to the polyAAc backbone by immersion of the hydrogel into a methanol solution containing a three-fold excess (relative to the amino-terminated NIPAAm) of coupling agent, dicyclohexylcarbodiimide (DCC). The coupling was carried out for 48 hours at room temperature. The resulting grafted hydrogel was washed with methanol and dried for 48 hours in air and for 24 hours under vacuum. The synthesis of the graft copolymer hydrogels is represented schematically in Figure 14. The degree of grafting was determined by comparing the dry weight of the pure polyAAc hydrogel with the product grafted hydrogel. The degree of grafting is represented graphically in Figure 15.

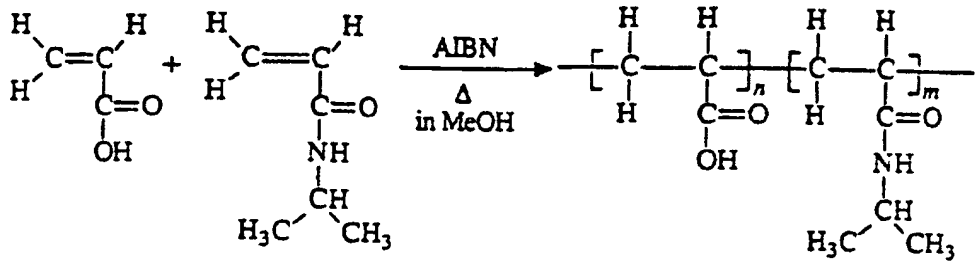
Generally, the percent grafting increased linearly with concentration of amino-terminated NIPAAm in solution with the initial reaction rate of the grafting being higher as the density of the cross-linking was decreased. A plateau of grafting level was reached for all samples.

B. Swelling of the Grafted Hydrogels

To determine the swelling characteristics of the grafted hydrogels prepared as described above, grafted hydrogel discs were incubated in 0.05 M phosphate buffer solution containing 0.15 M sodium chloride at pH 7.4 at 34°C. A Lab-Line water shaker-bath was used for temperature control. In a representative determination, a solution of the grafted hydrogel was shaken at 150 rpm and the swelling weights of the hydrogels measured by weighing the sample at various times. The weights were measured after removing the gel from the buffer, and blotting adhered water with weighing paper. The swelling ratios were determined as the swollen weight/dried weight (Wt/Wo) and are presented in Figure 16.

A. Synthesis and Characterization of Random Copolymers of NIPAAm and AAc

Random copolymers were synthesized by copolymerization of N-isopropylacrylamide and acrylic acid by standard radical polymerization procedures. Various random copolymers were prepared by varying the mole percent of NIPAAm monomer in the polymerization reaction. The synthesis of the random copolymer is represented schematically below.



The synthetic results and the temperature-sensitive behavior of the ransom copolymers is summarized in Table 7.

C. Drug Loading and Release from Random Copolymers

1. Drug Loading

Generally, random copolymer-drug complexes were prepared as described in Example 1C1.

The random copolymer-drug particles were prepared by dissolving 0.5 g of polymer and 5 mg of timolol (feed ratio is 1 wt%) in 10 mL of methanol and then precipitating into 500 mL of diethyl ether. The precipitate was then dried under vacuum overnight. The drug content in the particles were determined by dissolving the particles to form a solution, and spectroscopically measuring the absorbance of the drug in the solution at 294 nm. The results of drug loading for the random copolymer prepared as described above and the graft copolymers prepared as described in Example 3 are presented in Table 8.

Table 8.

Comparison of Random and Graft Copolymer Drug Loading

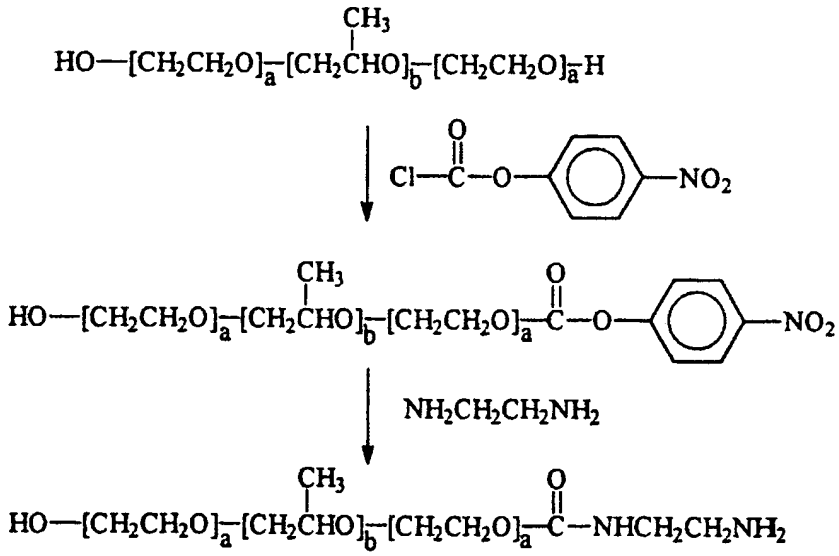
Polymer:	Random copolymer			Graft copolymer		
wt% NIPAAm in copolymer	26	32	39	20	30	50
Polymer added (g)	0.5	0.5	0.5	0.5	0.5	0.5
Drug added (mg)	5.0	5.0	5.0	5.0	5.0	5.0
Polymer recovery (% w/w)	94	94	94	74	90	90
Drug loaded (mg/g Polymer)	9.4	9.2	9.1	9.9	10.0	10.8

2. Drug Release

Generally, the measurement of drug released from the random copolymer-drug particles was determined as described in Example 1C2. The drug release results for the various random copolymers are compared to graft copolymers of similar composition at 34°C and 37°C in Figures 4 and 5, respectively. The results show that drug release from the random copolymers at 34°C is about twice as fast as release from the graft copolymers. For the random copolymers, the drug is completely released within 10 minutes. The results at 37°C are qualitatively similar to those at 34°C, although complete release of drug takes about 24 minutes.

The above block copolymers of EO/PO/EO were then derivatized to yield a reactive amino-terminal by a two step reaction First, 20g of L-122 (4 mmole) was reacted with 1.0g (5 mmole) of 4-nitrophenyl chloroformate in methyl chloride in the presence of triethylamine at room temperature for 4 hours to yield a 4-nitrophenyl formated-derivatized intermediate. This intermediate was recovered by extraction using petrolium ether for three times, resulting in 14 g of product with a yield of 72% by weight. In the second step, 10 g (2 mmole) of the intermediate was reacted with 0.36 g (6 mmole) of diaminoethlylene in methylene chloride at room temperature overnight. The amino-terminated L-122 derivative was recovered by extraction with petrolium ether for three times, dialysis against distilled water using a membrane with MW cut-off of 3500 for three days, and evaporated of water to obtain the product (8.8 g, yield of 88% by weight). Functionality of the amino-terminated derivative was determined by titration as 0.91 ± 0.1.

The other block copolymers of EO/PO/EO were similarly derivatized to yield a reactive amino-terminal by the reaction scheme illustrated below.



2. Synthesis of Graft Copolymers of EO/PO/EO-g-AAc

Graft copolymers of EO/PO/EO-g-AAc were prepared by coupling the reactive amino-terminals of the derivatized block copolymers of EO/PO/EO onto the homopolymer backbone of AAc. Specifically, reaction between the amino group of the amino-terminated EO/PO/EO derivative and a carboxyl group of AAc, in the presence of dicyclohexyl carbodiimide (DCC), resulted in amide bond formation. The reaction

L-122	20/80(wt%)	80
L-122	30/70(wt%)	68
L-122	40/60(wt%)	78
L-122	50/50(wt%)	65

B. Temperature-Sensitive Behavior of Graft Copolymers of EO/PO/EO-g-AAc

The graft copolymers of EO/PO/EO of this example form a translucent gel at approximately 32°C. Accordingly, rather than using an absorbance measurement for LCST, the solution-to-gel phase transition temperature was determined by measuring viscosity as a function of temperature by the following procedure.

A scintillation vail containing a stir bar was weighed, and 2.8 g of an aqueous solution containing 0.76% NaCl and 1.25% NaOH was added thereto. Next, 0.125 g of the L-122-30/70(wt%) graft copolymer was added, followed by 1.2 g of a 0.76% NaCl solution. The L-122-30/70(wt%) graft copolymer was dissolved by stirring the solution in an ice bath for about 2 hours, and then by keeping the scintillation vial in the refrigerator overnight. A sufficient amount of 1 N NaOH was added to the solution to yield a pH of 7.2. To this was added 0.05 g of 8.5% NaCl, and sufficient water was added to bring the solution to 5.0 g. The resulting solution contained 2.5% by weight of the L-122-30/70(wt%) graft copolymer, and had a pH of 7.2.

The viscosity of the solution was then measured at various temperatures ranging from 25°C to 40°C using a Brookfield DV III RV viscometer fitted with a CP-52 spindle. The temperature was controlled by circulating water from a constant temperature water bath through the jacket of the viscometer cup. About 0.6 ml of the solution was placed in the viscometer cup. The viscosity measurements were carried out at 0.1 rpm (shear rate 0.2/second) for 3 minutes at a fixed temperature. The viscosity value at the end of 3 minutes was recorded, and the results of these measurements are presented in Figure 20. As determined by this technique, the LCST of the L-122-30/70(wt%) graft copolymer was found to be 32°C at 25% of maximum viscosity.

C. Drug Loading and Release from Graft Copolymers of EO/PO/EO-g-AAc

Drug loading and release from the copolymer-drug mixture was determined by casting a film of a copolymer-drug mixture (containing 5% by weight timolol maleate) on a glass disk as disclosed in Example 1C2. In these experiments, the thickness of the films was ca. 150 μ, the diameter was ca. 0.54-0.58 mm, and the weight of each film was ca. 5 mg. The coated glass discs were suspended in PBS buffer (pH 7.4) at 34°C, and the amount of drug release was measured as a function of time. The results of this experiment are presented in Figures 21, 22 and 23.

Claims

1. A graft copolymer comprising a backbone pH-sensitive polymer component with a pendant temperature-sensitive polymer component grafted thereto, wherein the graft copolymer has a lower solution critical temperature ranging from 20°C to 40°C measured at a pH between 6.0 to 8.0.

2. A graft copolymer comprising a backbone temperature-sensitive polymer component with a pendant pH-sensitive polymer component grafted thereto, wherein the graft copolymer has a lower solution critical temperature ranging from 20°C to 40°C measured at a pH between 6.0 to 8.0.

3. A block copolymer comprising a pH-sensitive polymer component and a temperature-sensitive polymer component joined thereto, wherein the block copolymer has a lower solution critical temperature ranging from 20°C to 40°C measured at a pH between 6.0 to 8.0.

4. The copolymer of any one of claims 1, 2 or 3 wherein the lower critical solution temperature is determined at a pH between 7.0 to 7.8.

5. The copolymer of any one of claims 1, 2 or 3 wherein the lower solution critical temperature ranges from 26°C to 34°C.

6. The copolymer of any one of claims 1, 2 or 3 wherein the lower solution critical temperature ranges from 28°C to 32°C.

7. The copolymer of any one of claims 1, 2 or 3 wherein the pH-sensitive polymer component comprises a carboxylic acid-containing polymer.

8. The copolymer of claim 7 wherein the carboxylic acid-containing polymer is derived from polymerizable carboxylic acids selected from the group consisting of acrylic acid, methacrylic acid, ethacrylic acid, β-methylacrylic acid, cis-α-methylacrylic acid, trans-α-methylcrontic acid, α-butylcrontic acid, α-phenylacrylic acid, α-benxylacrylic acid, α-cyclohexylacrylic acid, β-phenylacrylic acid, coumaric acid and umbellic acid.

9. The copolymer of claim 78 wherein the carboxylic acid-containing polymer is carboxymethylcellulose.

22. A graft copolymer-drug mixture comprising a drug and a graft copolymer, wherein the graft copolymer comprises a backbone pH-sensitive polymer component with a pendant temperature-sensitive polymer component grafted thereto.

23.A graft copolymer-drug mixture comprising a drug and a graft copolymer, wherein the graft copolymer comprises a backbone temperature-sensitive polymer component with a pendant pH-sensitive polymer component grafted thereto.

24. A block copolymer-drug mixture comprising a drug and a block copolymer, wherein the block copolymer comprises a pH-sensitive polymer component and a temperature-sensitive polymer component joined thereto.

25. The copolymer-drug mixture of any one of claims 22, 23 or 24 wherein the copolymer has a lower solution critical temperature ranging from 20°C to 40°C measured at a pH between 4.0 and 8.0.

26. The copolymer-drug mixture of any one of claims 22, 23 or 24 wherein the mixture is in the form of a solid particle.

27. The copolymer-drug mixture of claim 26 wherein the solid particle is suspended in a pharmaceutically acceptable carrier.

28. The copolymer-drug mixture of any one of claims 22, 23 or 24 wherein the mixture is formulated as a liquid, gel or ointment.

29. The copolymer-drug mixture of claim 28 wherein the mixture is formulated as a liquid which gels upon administration to a treatment area.

30. A method for administering a drug to a treatment area, comprising applying to the treatment area a copolymer-drug mixture of any one of claims 22, 23 or 24.

31. The method of claim 30 wherein the copolymer-drug mixture is applied in the form of a solid particle.

32. The method of claim 31 wherein the solid particle is applied as a suspension within a pharmaceutically acceptable carrier.

43. A method of absorbing a solvent or solution, comprising exposing the hydrogel of any one of claims 35 or 36 to the solvent or solution and allowing the hydrogel to swell.

44. The method of claim 43 wherein the solvent or solution comprises a material selected from the group consisting of urine, feces, water, blood, brine and an ionic water solution.

45. The method of claim 43 wherein the swelling ratio of the hydrogel is not less than 15.

46. A diaper where a superabsorbant component comprises the hydrogel of any one of claims 35 or 36.

47. A copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 wherein the copolymer or hydrogel provides moisture to a treatment area.

48. A copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 wherein the copolymer or hydrogel retains moisture at a treatment area.

49. A copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 wherein the copolymer or hydrogel provides hydration to a treatment area.

50. A copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36 wherein at least one of the polymer components comprises a bioadhesive.

51. A cosmetic composition, a wound dressing, a pharmaceutical composition comprising a drug, an iontophoretic device, a monitoring electrode, an adhesive, a cream, a foam, a suppository, a tablet, a delivery gel, a device for nasal, vaginal, oral, ocular, rectal, dermal or otic delivery, or a laxative, comprising a copolymer or hydrogel of any one of claims 1, 2, 3, 22, 23, 24, 35 or 36.

52. A device for vaginal delivery of a drug according to claim 51 wherein the drug is selected from a spermicide, ovacide, antimicrobial, antifungal, prostaglandin, and steroidal or nonsteroidal fertility agent.

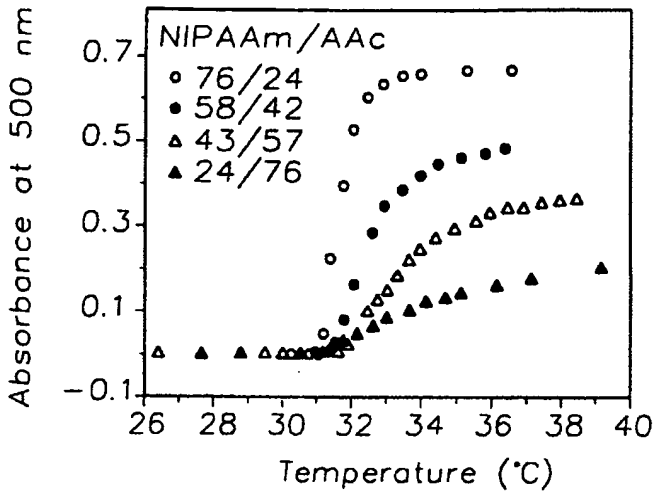

NIPAAm/AAc
76/24
58/42
43/57
24/76
Absorbance at 500 nm
0.7
0.5
0.3
0.1
−0.1
26 28 30 32 34 36 38 40
Temperature (°C)

Fig. 1

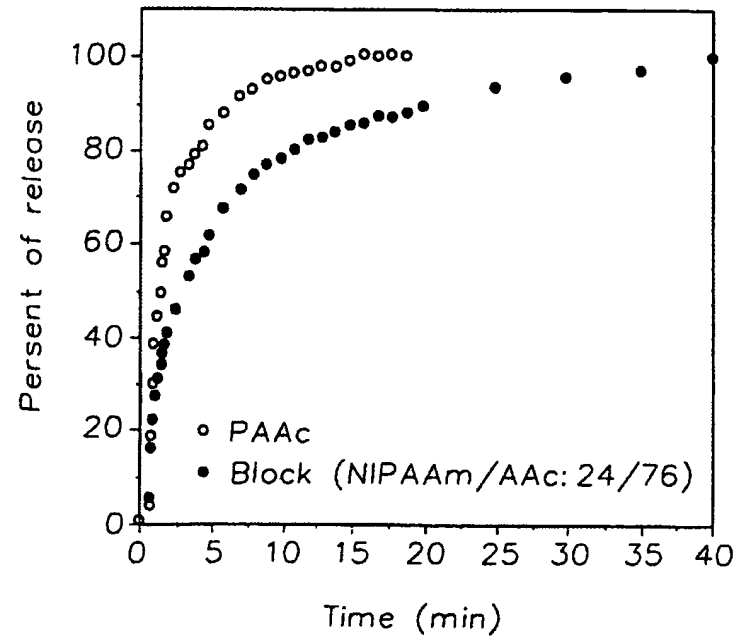

Persent of release
100
80
60
40
20
0
0 5 10 15 20 25 30 35 40
Time (min)
PAAc
Block (NIPAAm/AAc: 24/76)

Fig. 2

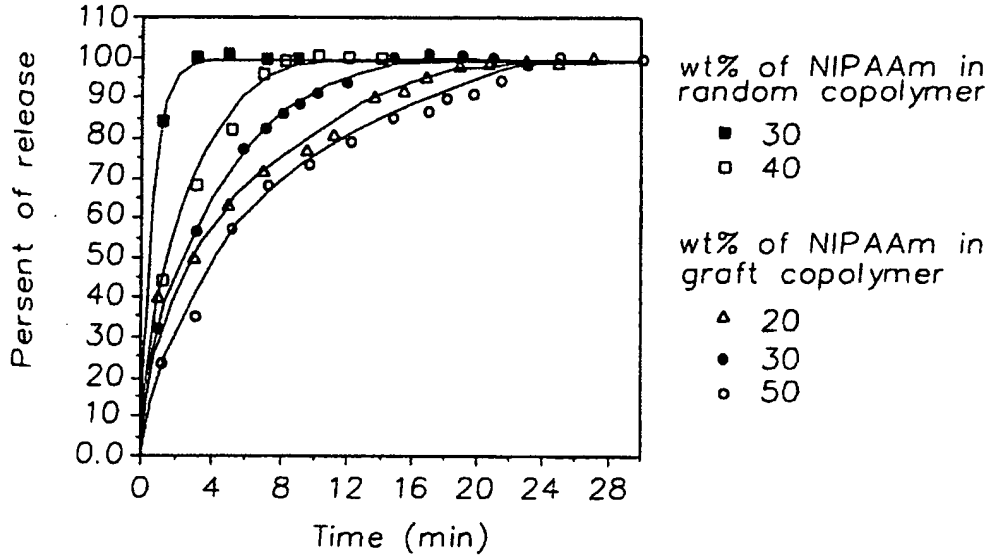

Persent of release
110
100
90
80
70
60
50
40
30
20
10
0.0
0
4
8
12
16
20
24
28
Time (min)
wt% of NIPAAm in random copolymer
30
40
wt% of NIPAAm in graft copolymer
20
30
50

Fig. 5

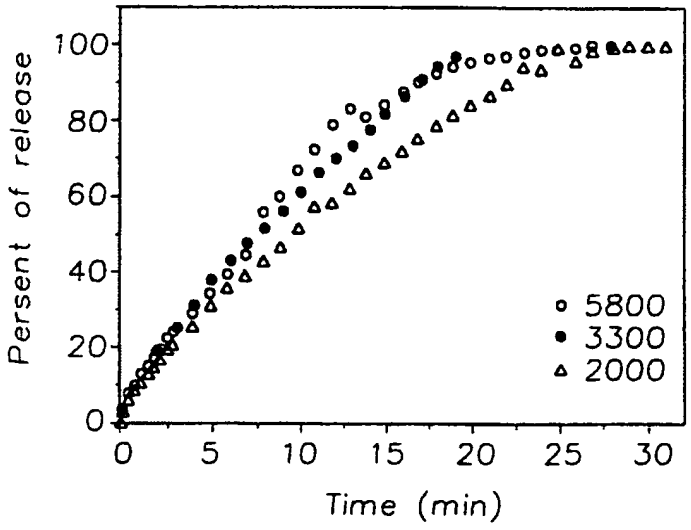

Persent of release
100
80
60
40
20
0
0
5
10
15
20
25
30
Time (min)
5800
3300
2000

Fig. 6

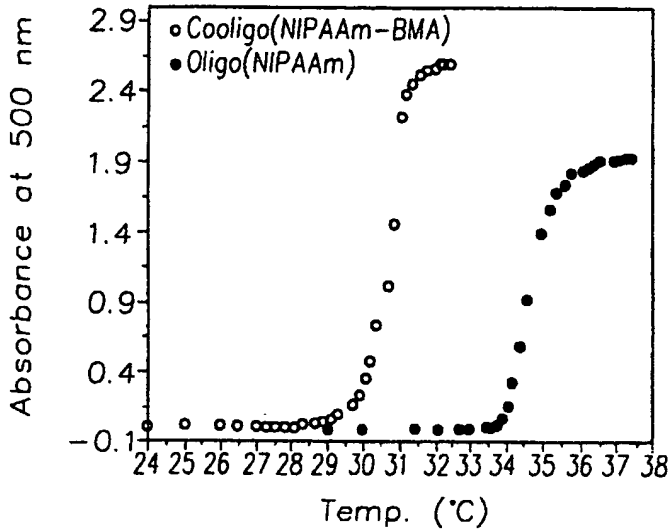

Cooligo(NIPAAm-BMA)
Oligo(NIPAAm)
Absorbance at 500 nm
2.9
2.4
1.9
1.4
0.9
0.4
-0.1
24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
Temp. (°C)

Fig. 9

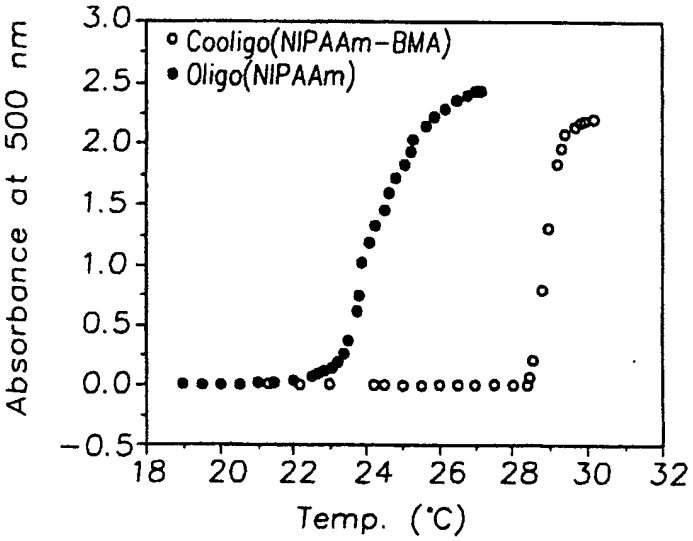

Cooligo(NIPAAm-BMA)
Oligo(NIPAAm)
Absorbance at 500 nm
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
18 20 22 24 26 28 30 32
Temp. (°C)

Fig. 10

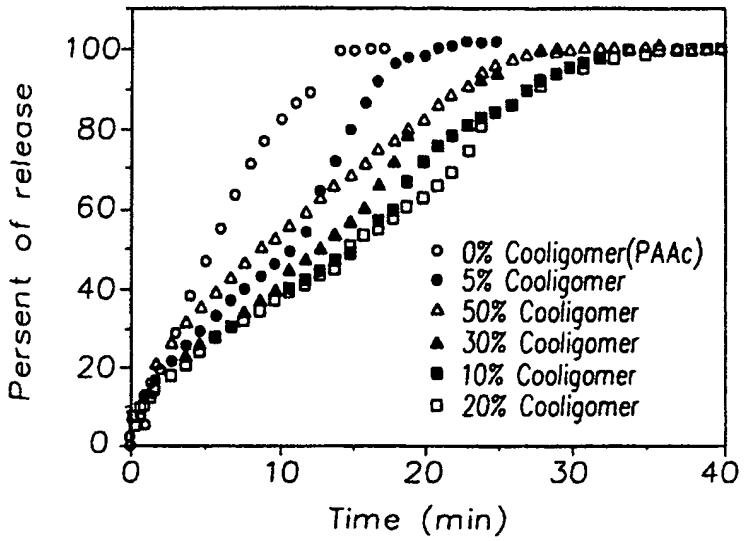

Persent of release
100
80
60
40
20
0
0
10
20
30
40
Time (min)
0% Cooligomer(PAAc)
5% Cooligomer
50% Cooligomer
30% Cooligomer
10% Cooligomer
20% Cooligomer

Fig. 13

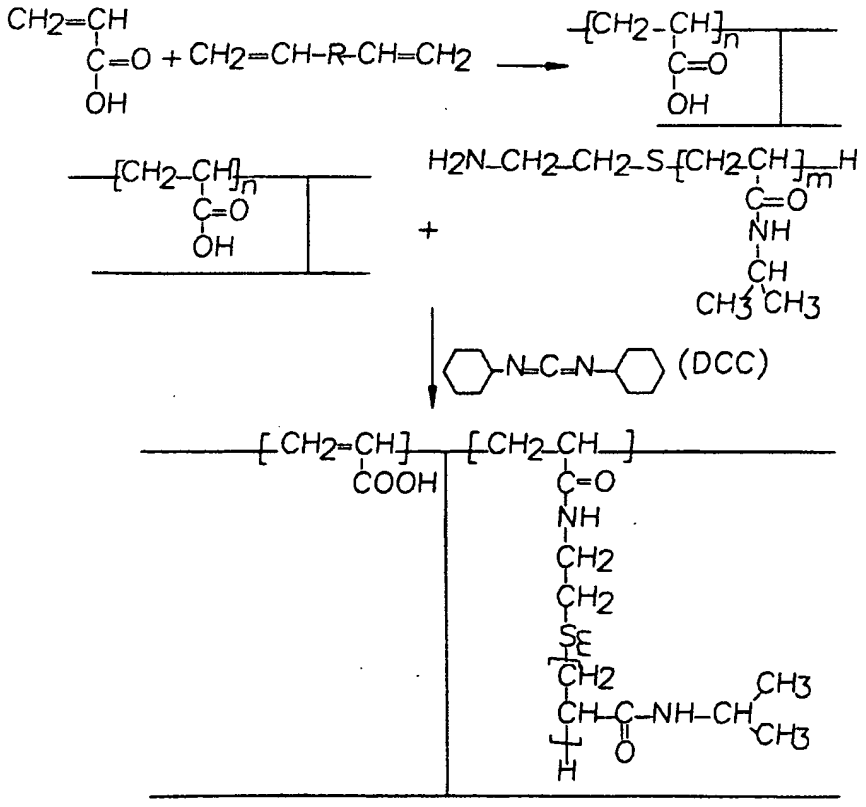

CH2=CH
C=O
OH
+ CH2=CH-R-CH=CH2
[CH2-CH]n
C=O
OH
H2N-CH2-CH2-S-[CH2-CH]m-H
C=O
NH
CH
CH3 CH3
(DCC)
[CH2=CH]
COOH
[CH2-CH]
C=O
NH
CH2
CH2
S
CH2
CH-C-NH-CH
CH3
CH3
O
H

Fig. 14

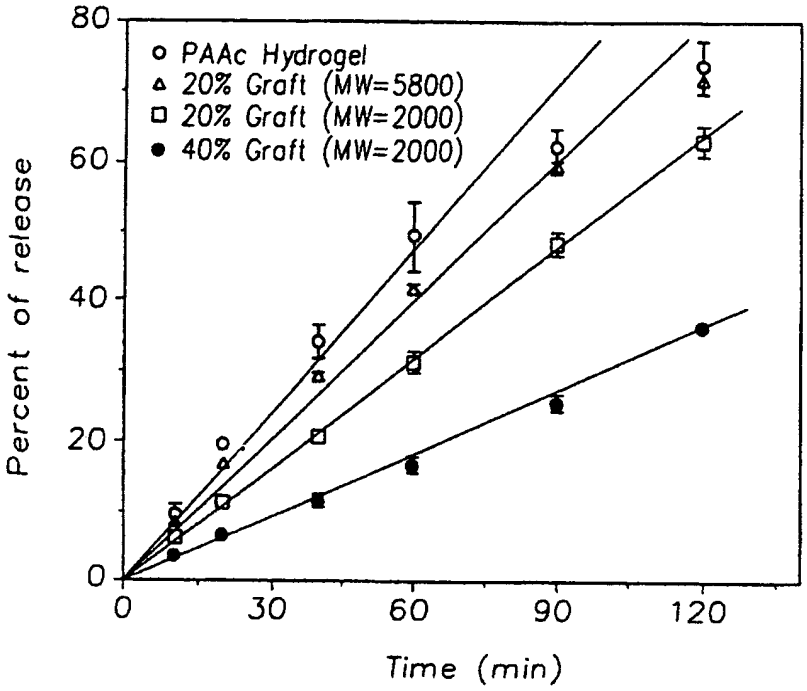

PAAc Hydrogel
20% Graft (MW=5800)
20% Graft (MW=2000)
40% Graft (MW=2000)
Percent of release
Time (min)
0
20
40
60
80
0
30
60
90
120

Fig. 17

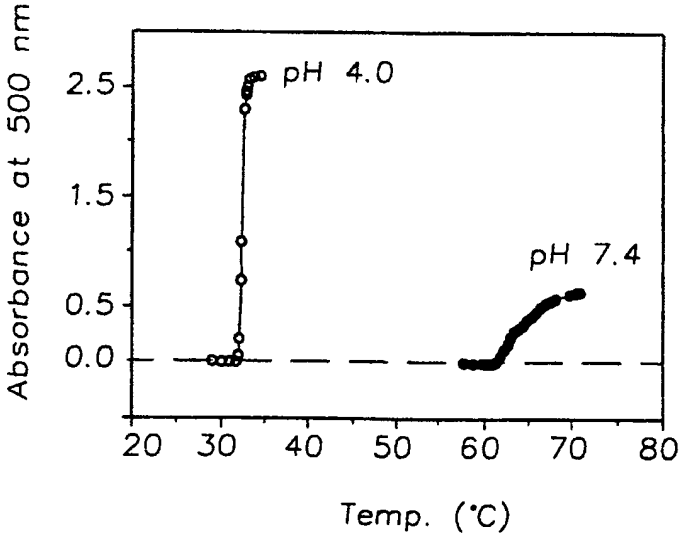

pH 4.0
pH 7.4
Absorbance at 500 nm
Temp. (°C)
0.0
0.5
1.5
2.5
20
30
40
50
60
70
80

Fig. 18

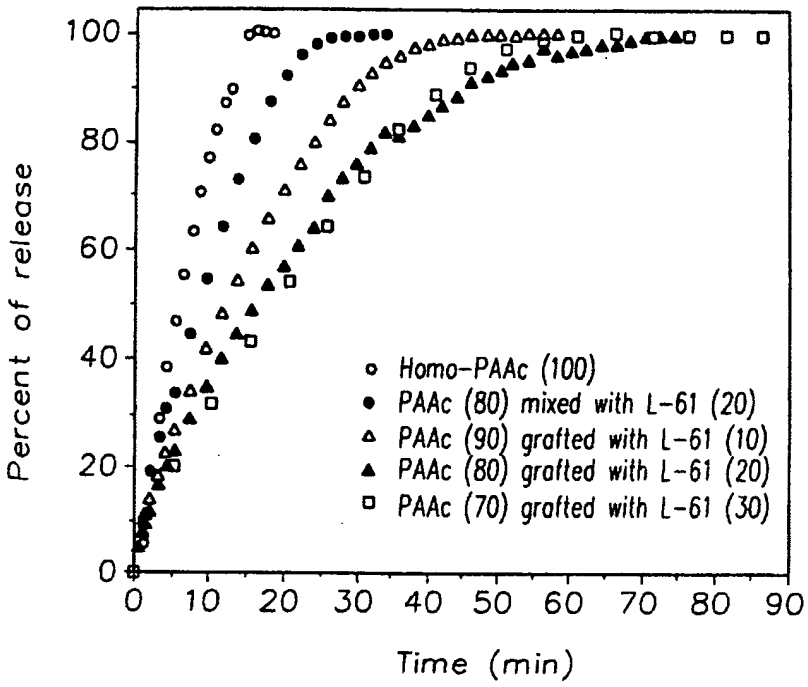

Percent of release
Time (min)
Homo-PAAc (100)
PAAc (80) mixed with L-61 (20)
PAAc (90) grafted with L-61 (10)
PAAc (80) grafted with L-61 (20)
PAAc (70) grafted with L-61 (30)

Fig. 21

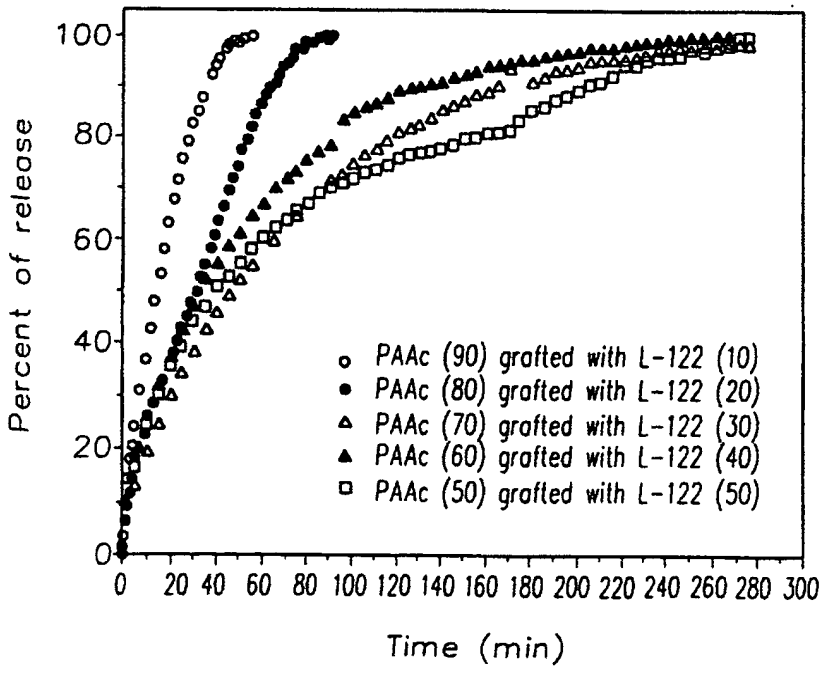

Percent of release
Time (min)
PAAc (90) grafted with L-122 (10)
PAAc (80) grafted with L-122 (20)
PAAc (70) grafted with L-122 (30)
PAAc (60) grafted with L-122 (40)
PAAc (50) grafted with L-122 (50)

Fig. 22